Manuscript title

Systematic literature review on the association between soundscape and ecological/human wellbeing

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ABSTRACT

Background. Wellbeing issues are increasingly incorporated within conservation biology and environmental sciences, both in academic research and in applied policies such as the global sustainable development plans. The role of landscape on human wellbeing has been widely reported, but a comprehensive understanding of the role of *soundscape* has yet to be explicated. Research on the influences of sound on wellbeing has been conducted across a range of disciplines, but integration of findings is impeded by linguistic and cultural differences across disciplinary boundaries. This study presents the largest systematic literature review (2499 publications) of research to date, addressing the association between soundscape and human/ecological wellbeing.

Method. It is divided in two components: 1. rapid visualisation of publication metrics using the software VOS Viewer, and 2. analysis of the categories of wellbeing associated with soundscape using the natural language processing platform, Method52. The first component presents network diagrams created from keyword searches and cited references (*lexical, temporal, spatial and source networks*) that explain the origin and evolution of the field, the influences between disciplines and the main contributors to the field. Research on the topic, occurring mostly between 2004 and 2016, evolved from a medical/physiological focus, into technological and psychological/social considerations, and finally into ecological/social research.

Results. The evolution of the field was associated with the diversification of terminology and the evolution of new branches of research. Moreover, research appears to have evolved from the study of particular associations between sound and health, to an integrative multidimensional field addressing soundscape and wellbeing, across human and non-human species, including ecologically based studies. The second component includes a trained classifier that categorizes publications, based on keywords analysis, into three frameworks for understanding the association between soundscape and wellbeing: 'Human health', 'Social and Cultural wellness' and 'Ecological integrity'.

Conclusion. This novel methodology is shown to be an effective tool for analysing large collections of data in short periods of time. In order to address the gaps found during the study, it is recommended to increase research conducted in and by non-western societies and in non-English languages, and the exploration of ecological and sociocultural aspects of wellbeing associated with soundscape.

Keywords: health, sounds, welfare, ecological health, noise, wellbeing, machine learning, bibliometric networks

1. INTRODUCTION

1.1. The study of Human Wellbeing in Conservation and Environmental Sciences

The importance of addressing wellbeing issues as part of global strategies and action plans for sustainable development and biodiversity conservation is increasingly recognized. For example, the Intergovernmental Panel on Climate Change (2014) and the Millennium Ecosystem Assessment (2015) reports highlight consequences of global environmental change on human wellbeing and the importance of considering it a priority. In addition, the Sustainable Development Goals (SDGs) include the promotion of human wellbeing and healthy lives as part of their 2030 Agenda. Within conservation and other environmental sciences, there is an increasing trend for studies which incorporate social and ecological concerns, and consider the impact of landscape disturbance or nature conservation on human wellbeing (e.g. McKinnon et al., 2016, Mascia et al., 2014, Milner-Gulland et al., 2014a). With the study of the impact of environmental change on human wellbeing, new perspectives in academic research are emerging. For example, most studies in ecology and conservation sciences describe humans as a 'negative influence' on ecosystem integrity (e.g. Bennett and Robinson, 2000, Peres, 2000, Goudie, 2013, Halpern et al., 2008, Nyssen et al., 2004) and not as an 'affected component' of the ecosystem. This change in paradigm, from conceiving humans as detrimental to nature, to an affected part of the ecosystem, is likely to have repercussions for future decisions, practices and management plans. For example, it has been reported that the loss of ecosystems, species, populations, and genetic diversity has implications for human health by altering the goods and services provided by natural ecosystems, such as: decreasing global food productivity, eliminating species important for medical use, increasing the rate of infection diseases, and others (Chivian, 2002). Hence, the integration of human perspectives in ecological/conservation sciences might stimulate the generation of strategies and action plans that aim to maintain ecosystem integrity, of which humans are an integral part.

The study of the role of the natural environment on human wellbeing is complex. Not least because definitions of wellbeing vary; however, even though there is a current lack of consensus on how to quantify wellbeing, a few promising approaches have been proposed (e.g. Dodge et al., 2012, Milner-Gulland et al., 2014a, Bottrill et al., 2014b). A review by McKinnon et al. (2016), found that nature conservation was associated with 9 aspects of wellbeing and recommended further research to better understand these relationships: *Economic living standards*, *Material living standards, Health, Education, Social relations, Security and Safety, Governance, Subjective wellbeing, Culture and Spirituality* and *Freedom of choice and action.*

1.2. Evaluating the associations between Soundscape and Wellbeing

In addition to the role of landscape, the role of soundscape in human wellbeing is now recognised (Sattar et al., 2016). Soundscape has been defined as all the sounds emanating from a landscape, including multiple sonic sources: geophony (geophysically produced sounds), biophony (biologically produced sounds) and anthrophony (sounds produced by humans)(Pijanowski et al., 2011b). The study of the effects of soundscape, or of specific sonic sources, on wellbeing has been of interest in a wide range of fields such as psychoacoustics, medical sciences, acoustic ecology, soundscape ecology, ethnomusicology, bioacoustics, engineering, and others. However, information is scattered across disciplines and integration across them is difficult, as specialist academic language can sometimes be a barrier (Nielsen-Pincus et al. (2007) and Klein (1984). Furthermore, most of the work has been centred around quite specific facets of sound, and human wellbeing: the effects of noise and quietness on health (Gidlof-Gunnarsson and Ohrstrom, 2007, Münzel et al., 2014, Booi and van den Berg, 2012, Van Der Eerden et al., 2013, Van Renterghem and Botteldooren, 2012), comfort and annoyance (Gidlof-Gunnarsson and Ohrstrom, 2007, Gidlof-Gunnarsson and Ohrstrom, 2010, Van Kempen et al., 2009, Yang and Kang, 2005) and productivity (Hume, 2010, Mak and Lui, 2012, Sakuma and Kaminao, 2010).

Research has also been carried out on the influence of sounds at individual, social and cultural levels. For example, the pioneers of soundscape studies, Barry Truax (Truax, 1978) and Murray Schafer (Schafer, 1994), started by studying the relationship and interactions between humans and the sonic environment, including musical orchestration, aural awareness, and acoustic design (Pijanowski et al., 2011b). They brought new concepts to the field that highlighted the consequences of industrialization (and of noise pollution) on the quality of a sonic environment. Since then, it has been recognized that not only humans, but also the natural environment, has been impacted by habitat modification (Schafer, 1994).

More recently, the field of *ecoacoustics* has emerged, which considers sound as a component and an indicator of ecological processes occurring in an ecosystem (Sueur and Farina, 2015). Sounds are the material from which different ecological processes can be inferred to investigate the ecology of populations, communities and landscapes (Sueur and Farina, 2015). This discipline harbours the field of soundscape ecology, which investigates how sound in landscapes can be used to understand coupled natural-human dynamics across different spatial and temporal scales (Pijanowski et al., 2011b). Several ecological hypotheses underpin this research, such as the Acoustic Niche

Hypothesis[1] (ANH)(Krause, 1987), the Acoustic Adaptation Hypothesis[2] (AAH)(Daniel and Blumstein, 1998) and the Morphological Adaptation Hypothesis[3] (MAH)(Podos, 2001). These postulations explain how the soundscape becomes structured through the evolutionary pressures that occur within natural acoustic communities according to physical structure, the adaptive mechanisms of sound production and transmission, the reduction of acoustic competition, and the behavioural processes associated with vocalizing species (Farina, 2014b). By studying these mechanisms and impacts due to environmental changes, ecological research has started to explore associations between soundscape and environmental health. Soundscape ecology promotes research not only of the ecological but also the social associations of soundscape with wellbeing (Pijanowski, 2011).

An important contribution highlighting the ecological and social importance of preserving soundscapes was provided in a review by Dumyahn and Pijanowski (2011). They recognized 5 soundscape values and benefits of 'quality soundscapes': *Human wellbeing, Wildlife wellbeing, Sense of place, Landscape interactions,* and *Ecological integrity*. However, this proposal was based on a reduced number of publications (<100) and might not cover all knowledge generated across all disciplines. For example, Devadoss (2017) examines additional roles of soundscape in human identity, sense of belonging and community, which are not mentioned in the list. The need for more research on the ecological and social values associated with soundscapes has been identified (Dumyahn and Pijanowski, 2011).

The purpose of this study was to synthesise current cross-disciplinary knowledge around the associations between soundscape and wellbeing by integrating existing research into human and ecological wellbeing. The aim was to generate a corpus of synthethised information on the topic that facilitates comprehension of what has been done to date, circumventing the barriers of academic language. This study aims to contribute to soundscape ecology or ecoacoustics, to promote the integrated study of soundscape, wellbeing and soundscape conservation.

The main questions addressed by the analysis were:

[1] The ANH describes how acoustic signals are shaped in an interspecific arrangement, according to the competition model, in which each species occupies a specific space in the auditory spectrum in order to minimize spectral or temporal overlaps.

[2] The AAH explains how animal signals are moulded according to their intrinsic physical features (e.g. length of trachea) and also by the influence of environment properties.

[3] The MAH refers to the role of the body size as a constraint of the vocalization organs and their acoustic performance.

1. What is the state of knowledge in the field of soundscape and wellbeing? How was the field born and how has it evolved over time?

2. Which types of associations between soundscape and wellbeing have been described to date? What are the most relevant concepts and linkages?

3. Which areas are untouched or under-researched and require future investigation?

2. MATERIALS & METHODS

A systematic literature review was carried out based on data compiled from academic literature on the topic of 'soundscape and its associations with wellbeing'. This is comprised of two components: 1. analysis of publication metrics; 2. analysis of categories of wellbeing associated with soundscape.

2.1. Corpus construction

In order to compile publications on the topic of research, it was necessary to identify a set of words ('topic words') that were used to conduct a search within abstracts, titles or keywords of online publication databases. In order to compile a comprehensive list of topic words for conducting the literature search, synonyms of the words 'soundscape' and 'wellbeing' were identified. The latter search strategy has also been used in Woodhouse et al. (2015) and Coralie et al. (2015) for conducting systematic literature reviews on similar topics. In the case of 'wellbeing', 12 synonyms (listed below) were found in online dictionaries (Thesaurus.com and WordReference.com). These terms were considered appropriate for the search as they include broader definitions of 'wellbeing' (Šprah et al. 2014) and are not restrictive, considering the diversified use of 'wellbeing' across disciplines (Dodge et al. 2012; Milner-Gulland et al. 2014). 'Soundscape' synonyms were searched for in the same online dictionaries. However, these synonyms were not included as they were considered inappropriate for the search strategy (e.g. they included terms such as 'landscape', 'sound wave' and others which diverged from the focus of this study). In order to find more suitable synonyms, a brief review of related terms used in relevant publications on the topic was carried out: 'soundscape' appeared as a term in the late 1970s (by Murray Schafer), but it also has been referred to in literature as 'sonic environment' (Truax 1978) or 'acoustic environment' (International Organization for Standardization SO 12913-1:2014). Therefore, the three last mentioned terms were selected for the search.

A search string comprising the following terms was used to query SciVerse's *Scopus* and Tomson Reuters *Web of Science*, both peer-reviewed publication databases: "'soundscape' OR 'sonic environment' OR 'acoustic environment' AND 'wellbeing' OR 'well-being' OR 'comfort' OR 'happiness' OR 'health' OR 'prosperity' OR 'welfare' OR 'advantage' OR 'benefit' OR 'ease' OR

'good' OR 'wealth' OR 'pleasure'". The search string in SCOPUS and Web of Science was based on the database titles, abstracts and keywords. The results from both bibliographic databases were combined into one database. In order to evaluate whether the search strategy was effective, the compilation was compared to a comprehensive personal database of publications compiled by the author on the same topic. As most of publications from the personal compilation were present in the combined database used for this study, the search strategy was considered appropriate for the analysis.

2.2. Evaluation of publication metrics

In order to provide an overview of the linkages between research across disciplines, bibliometric networks were constructed and viewed using VOS Viewer (version 1.6.5). Four maps were generated: 1. A Lexical network, 2. A Temporal network, 3. A Spatial network, and 4. A Source network:

The lexical network was generated in order to evaluate how the field of research has grown, and what the concepts most associated between soundscape and wellbeing are. This was conducted by analysing the 'keyword co-occurrence' among the database publications. 'Co-occurrence' refers to the number of times one keyword appears in close relation with another. In this network map terms are located at different coordinates in 2D space, according to the number of co-occurrences of a term (keyword) and its relationship with other terms. Objects are located close to their 'ideal coordinates'. The ideal coordinates of an object *i* are defined as a weighted average of the coordinates of all other objects, where the coordinates of objects more similar to object *i* are given higher weight in the calculation of the weighted average (van Eck & Waltman 2007). Hence, the distance between two terms can be interpreted as an indication of the relatedness of the terms: the smaller the distance between them, the more strongly they are likely to be related to each other (Van Eck & Waltman 2011). Each term has a specific label and circle size depending on a measured weight, which is obtained by calculating the number of links of an item and the total strength of the links of an item (Van Eck & Waltman 2013). Terms are grouped in clusters - shown in different colours - of closely-related terms, based on the weighted and parameterized variant modularity function of Newman & Girvan (2004). A minimum number of co-occurrences of a keyword was used as a threshold, as recommended in Van Eck & Waltman (2013) (≥10).

A Temporal network was created in order to explore the temporal dynamics of the field, using the same clustered network but presented within a time period, based on the average number of publications per year. A Spatial network, was created in order to evaluate geographical patterns in contributions to the field, based on the average number of publications per country. A minimum number of publications per country (≥5) was used as a threshold, as recommended in Van Eck & Waltman (2013). Finally a Source network was created in order to analyse the sources (i.e.

publication types) that have contributed to the evolution of the field, through an analysis of source citations. A minimum number of documents/citations of a source (≥5) were used as a threshold for creating the map of source citation oand linkages between them. Additionally, a temporal analysis was integrated in order to visualize contributions from each source over time (based on the average number of publications per year).

2.3. Definition of categories of wellbeing associated with soundscape

To further explore lexical associations between soundscape and wellbeing, a supervised classifier was built with Method52 (version6.1.)(Wibberley et al. 2014). Method52 is a tool for collecting, processing and exploring large collections of text documents. It uses natural language processing, which allows machines to infer patterns from a trained dataset created by the analyst, and to make general predictions about the whole dataset (Nadkarni et al. 2011). For this study a classifier was built in order to automatically categorize the compiled publications into defined categories of wellbeing. A training process was used to create the classifier which consisted of: 1. Defining categories of wellbeing, 2. Manual labelling of a random subset (300 samples) of publications into categories of wellbeing (called correct answers or 'gold-standard dataset'), 2. Training the classifier by labelling a smaller subset of samples (200 samples) and measuring the model performance using the gold-standard dataset (see Section 3.4. for details), and 3. Aggregating more samples to the training data to enhance the performance of the model.

Wellbeing categories were initially pre-defined based on domains of wellbeing reported in similar works (Bottrill et al. 2014a; Woodhouse et al. 2015), and refined during the interactive-learning process (details in results). 'Author-keywords' or 'index-keywords' (when the latter were missing) were used for the classification of each publication into a category. When the keywords of a publication were not clear enough to categorize it, the whole abstract was read. The addition of more samples to the training data was decided based on classifier performance scores; if the performance scores of the model were poor, more training data was added until the model reached acceptable performance scores. The performance of the classifier was evaluated using the F-Score (*Precision* * *Recall*) of each category and overall classifier *Accuracy*, with the training dataset. *Precision* evaluates the proportion of documents considered by the classifier as true positive (*True Positive/True Positive + True False*); *Recall* measures the proportion of all relevant documents classified as relevant (*True Positive/True Positive + False Negative*); *Accuracy* assesses the proportion of documents assigned to a correct category (*True Positive/True Positive +True Negative+ False Positive+ False Negative*). Scores with a performance higher than 50%, were considered good, following the criteria of Wibberley et al. (2014).

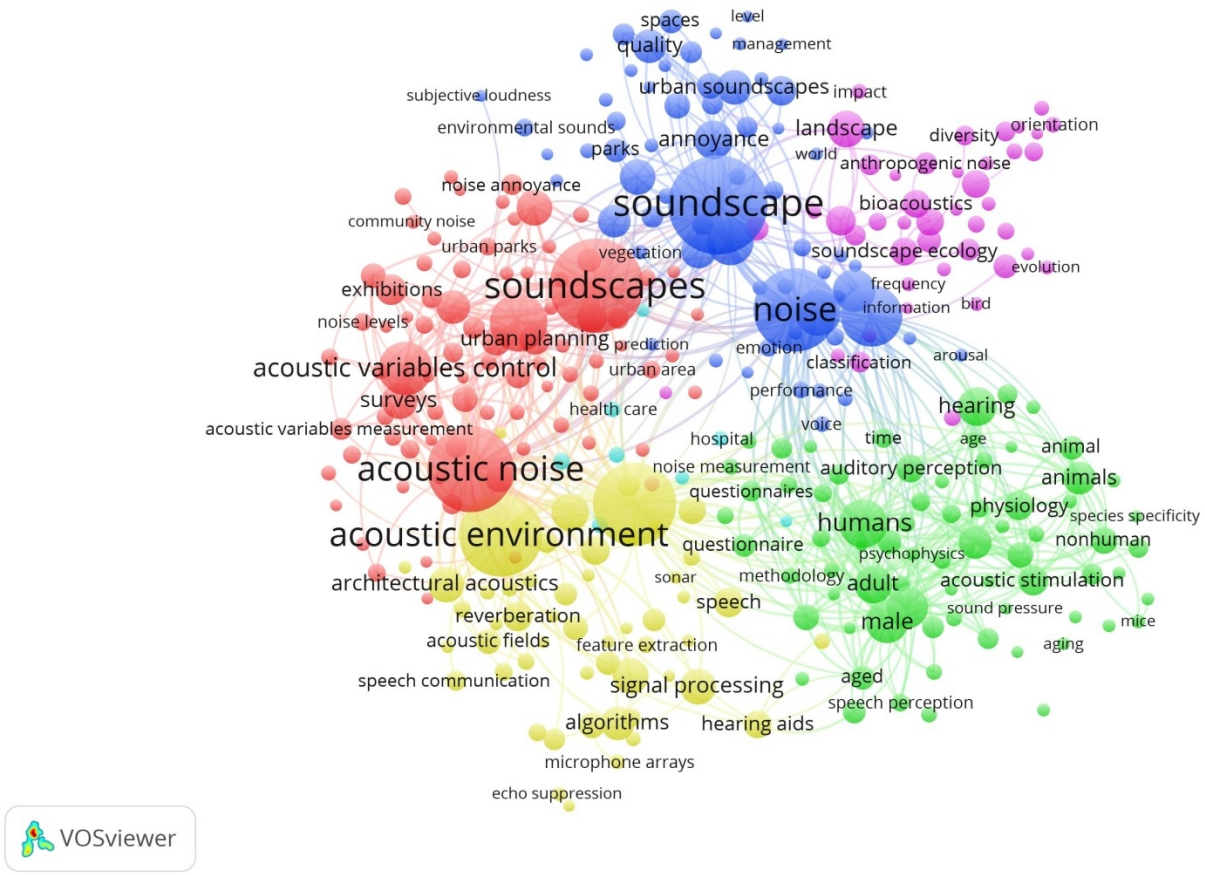
Classification of the compiled dataset was evaluated in a temporal domain (number of documents per year) in order to visualize how much each topic has been studied over time. Finally, a conceptual map of the association between 'soundscape' and 'wellbeing' was built by using the 'author-keywords' or 'index-keywords' list obtained during the classification of the compiled dataset. Terms that were duplicates or not self-explanatory, non-adjectives and/or not descriptive were removed from the list.

3. RESULTS

3.1. Lexical network

The final corpus consisted of 2379 articles (SCOPUS=1144; Web of Science=1235. Supplemental 1). The keyword co-occurrence analysis found 331 terms that meet the threshold (number of co-occurrences of a keyword ≥10). Fig. 1A shows a network of terms grouped into 6 clusters (see bibliographic metrics in Supplemental 2). Each cluster comprised a list of terms that were classified into general subjects, categorized as:

1. (Green) Medical/Physiological research: groups words which are lexically related to sense of hearing, and human/animal physiology research
2. (Yellow) Technological/Medical applications: comprises terms associated with the development of acoustic technologies and research into the properties of sound.
3. (Red) Acoustic perception research I: gathers terms related to acoustic assessment and sound measurement based on psychological research, especially focusing on 'noise' and 'urban' areas.
4. (Blue) Acoustic perception research II: includes terms that reflect broader research on soundscape perception and integrates a range of cultural/social aspects (e.g. tranquillity, identity, memory). This category differentiates from ´Acoustic perception research I´ because it is more focused on community, rather than individual levels, and include perspectives not only related to psychological research.
5. (Purple) Ecological research: gathers terms based on ecological research, especially in ecologically relevant descriptive patterns and noise
6. (Light Blue) Health care: contains terms associated with the application of research in health care practices.



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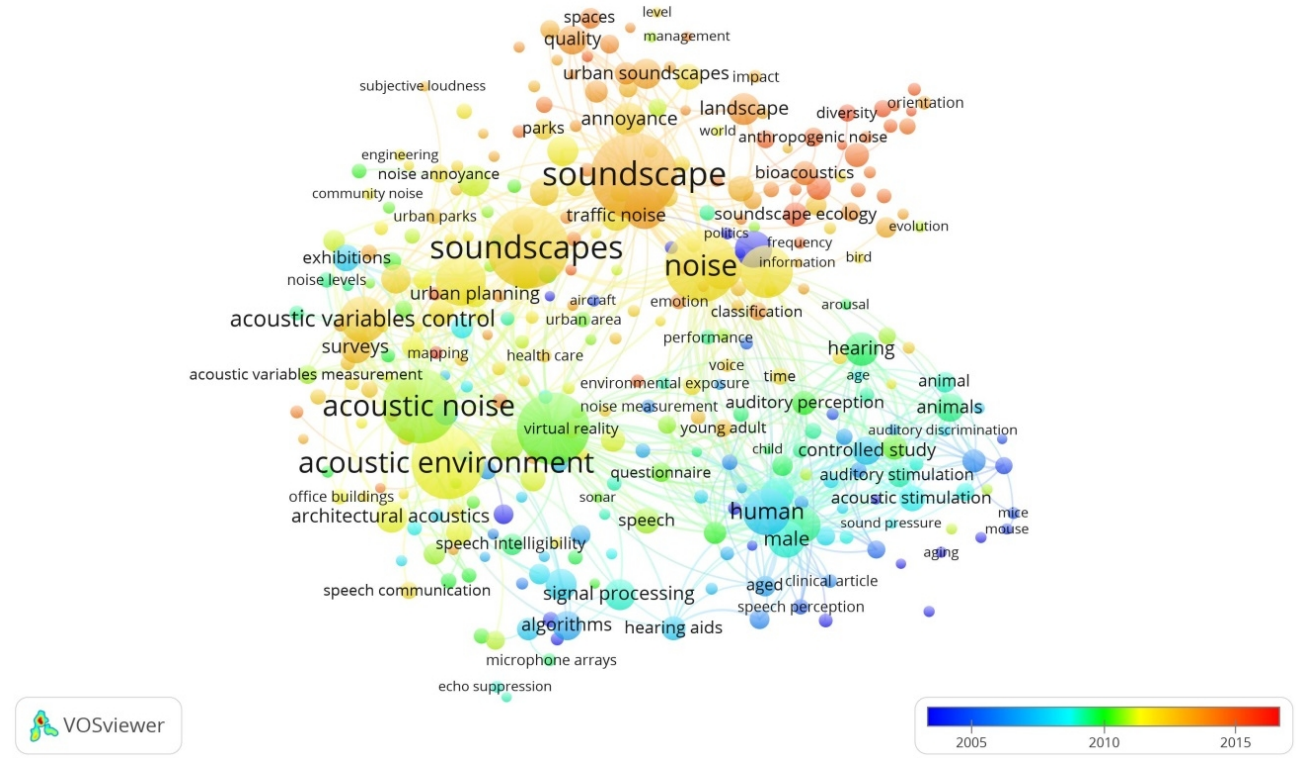


B

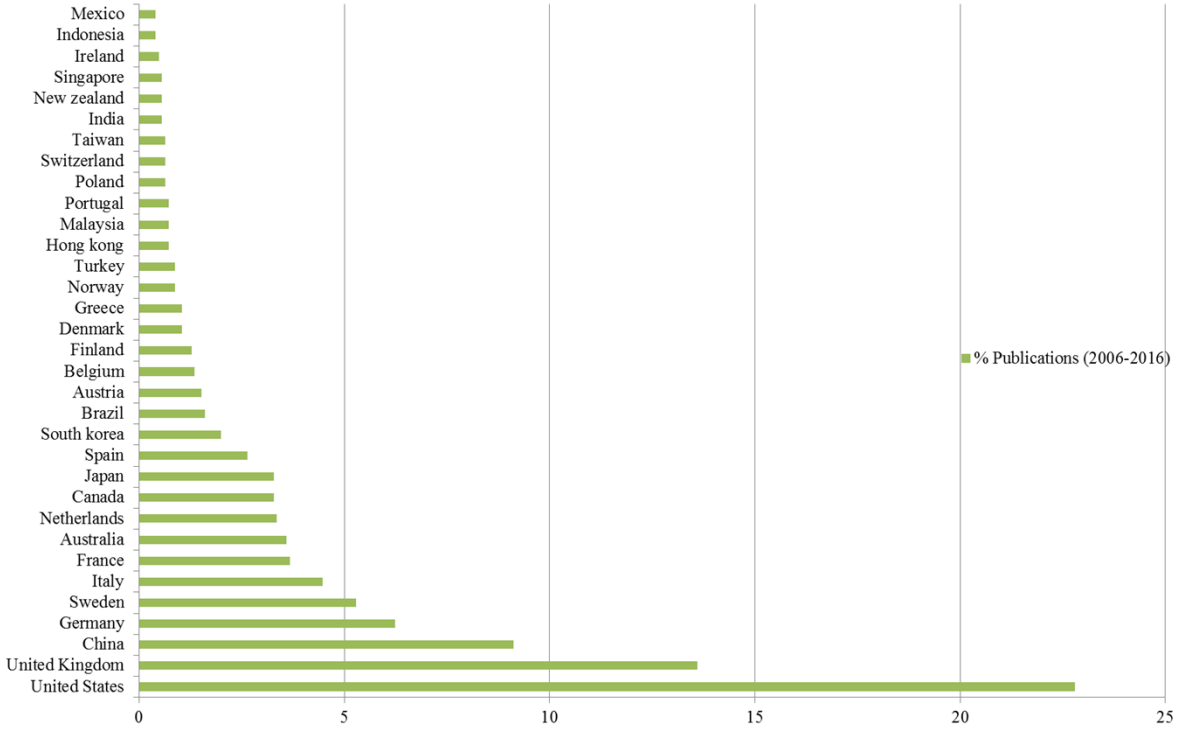
Figure 1. Network of the co-occurrence of keywords (items) in literature based on the association between 'soundscape' and 'wellbeing'. A) coloured by clusters, B) coloured by year of publication (2004-2016).

3.2. Temporal network

As shown in Figure 1B, most research on the topic has occurred over a period of 15 years, between 2004 and 2016. Terminology associated initially with the field suggests how research was mostly focused within the medical/physiological realm and the sense of hearing (i.e. physical health). At the same time, vocabulary seems to have evolved within the branch of acoustic technology – especially hearing/speech research, and other acoustic sciences from 2005-2009. From 2010, a new lexicon associated with the study of human perception of sound within psychological research emerges. This is followed by the evolution of other terms that develop a deeper understanding of the perception and influence of sound and soundscape for humans in 2013-2014 (e.g. soundscape, quality, urban planning). Finally, the development of soundscape ecology within biological sciences can be observed, with terms describing the fields of research involving environmental patterns and ecological impacts of noise (2014-2015).

3.3. Spatial network

The 34 countries, out of a total 94, that met the threshold criterion (number of documents of a country ≥5) are shown in Figure 2A (see also Supplemental 3). According to the analysis, most of the research has been conducted in institutions from 'developed countries' (N=30, 88.23%), following the criteria of the Global Human Development Report (UNDP 2016), during the period 2006-2016. The United States made the largest contribution (22.08%), followed by United Kingdom (13.6%), China (9.12%), Germany (6.24%) and other European countries (≤5% each). The temporal network, based on the average publications per year (fig. 2B), shows that United States and Japan were the pioneers of the research (2006-2008), followed by other European countries (France, Belgium, Finland, Sweden and Portugal), United Kingdom, Hong Kong and Canada (2009-2011). Afterwards, other European countries (Germany, Switzerland, Netherlands, Poland, Austria, Italy, Spain, Norway, Denmark and Greece), Asiatic countries (China, South Korea, Turkey), and South American countries (Brazil and Mexico) contributed to the field (2011-2012). From 2013-2015 other Asiatic countries (Taiwan, Hong Kong, Indonesia, Singapore and India), New Zealand and Ireland have also conducted research on the topic.



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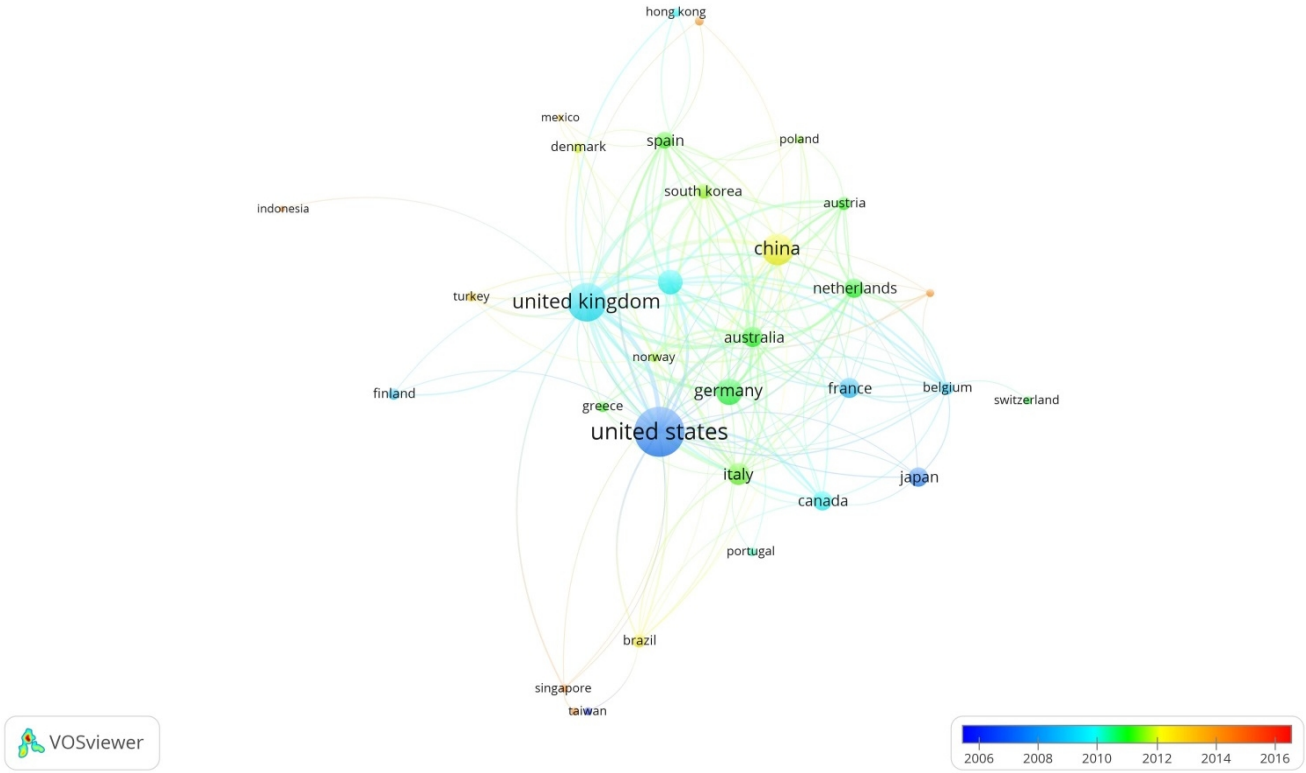


B

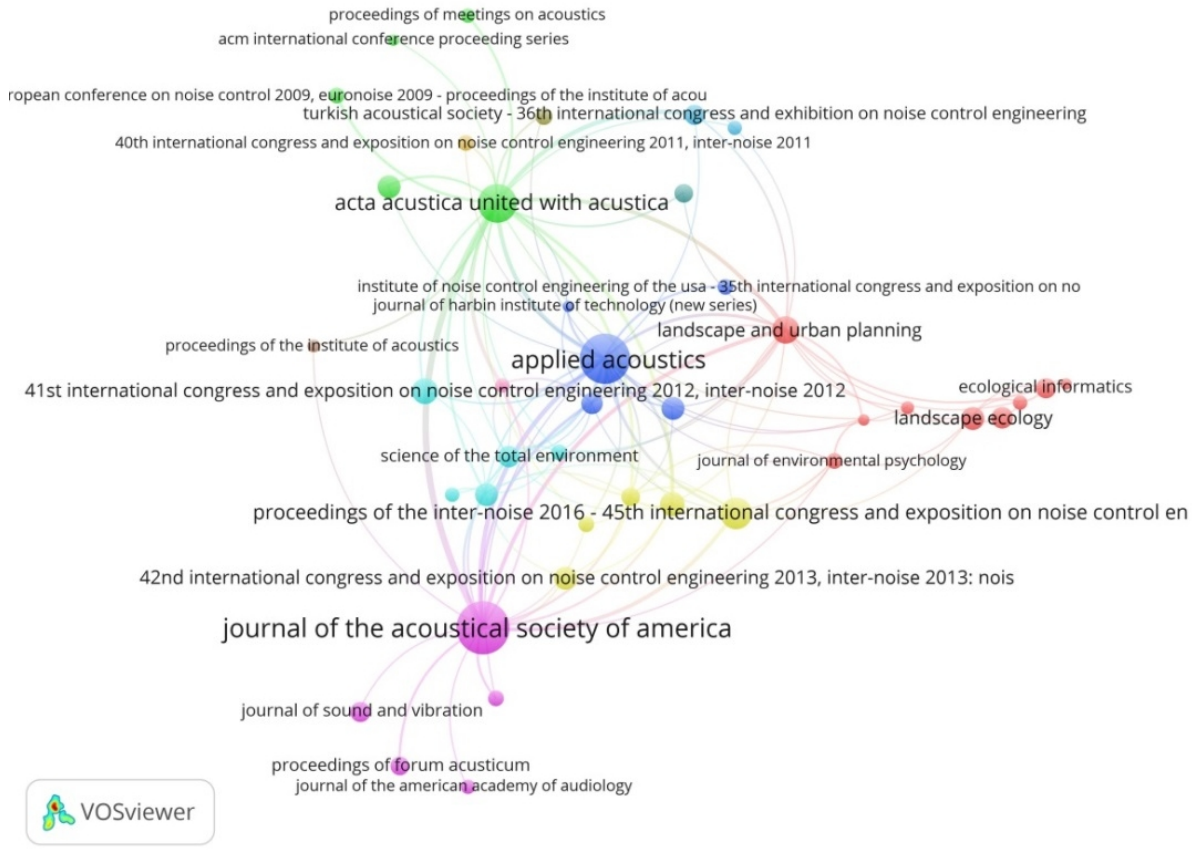
Figure 2. Countries that have contributed to literature based on the association between 'soundscape' and 'wellbeing', between 2004 and 2016: A) countries are displayed along the Y axis and number of publications along the X axis, B) spatial network based on number of documents cited by countries (average publications per year).

3.4. Citation Source network

Analysis of citation sources (fig. 3A) illustrates that there are 5 main clusters. Of 1180 sources found, 86 met the threshold (minimum number of document of a source ≥5) (Supplemental 4). Clusters were classified into the following categories: 1. Ecological and environmental sciences (red), 2. Engineering, noise control and acoustics (green colour), 2. Applied acoustics and engineering (blue), 3. Noise control and environmental research (yellow), 4. Acoustics and audiology (purple), and 5. Sound and noise control science research (light-blue). The most dominant contributors to the field have been the Journal of the Acoustical Society of America (8.98%) and Applied Acoustics (7.90%), followed by Acta Acustica United with Acustica (4.68%), Proceeding of Inter-noise 2016 (3.12%) and Landscape and Urban Planning (2.34%).

Temporal analysis (Fig. 3B) shows how research into soundscape has evolved through distinct research fields. Initial contributions to the field were conducted by journals on Acoustics and

international meetings/conferences on Engineering, and were focused on noise control. This was followed by further contributions by other journals on Acoustics, but also by the incorporation of Environmental and Public Health literature (2006-2011). Following that period, there appears to be an integration of publications based on Applied Acoustics and Landscape Architecture. At the same time, other conference journals, focused on noise control, continued to contribute to the field. In recent years new sources based on Ecological and Landscape research appear to have contributed to the field (2012-2016).



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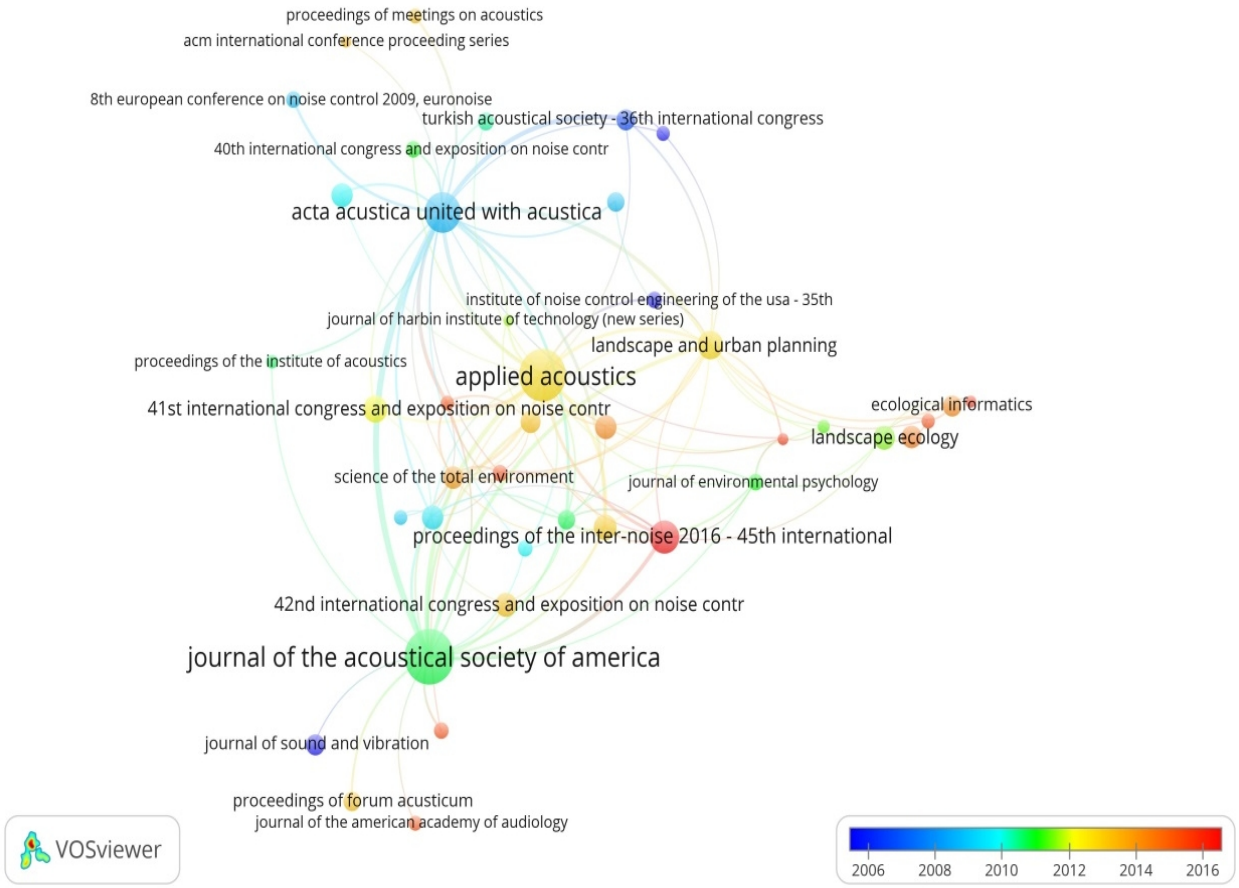

B

Figure 3. Spatial network showing the main contributors to the field on the association between 'soundscape' and 'wellbeing, based on number of documents by citation sources. A) coloured by clusters, B) coloured by year of publication.

3.4. Lexical classifier: Categories associated with 'wellbeing' and Conceptual Map

Five categories, or domains of wellbeing were initially included in the analysis: 1. 'Health', 2. 'Spiritual and Cultural wellness', 3. 'Freedom and Social wellness', 4. 'Animal health' and 5. 'Ecological integrity'. Because the number of samples in 'Freedom and Social wellness' and 'Animal health' categories was low, and the evaluation of the classifier gave poor scores (i.e. low F-scores), these categories were combined into one category. The refined categories used for creating the classifier were: 1. 'Health', 2. 'Cultural and Social wellness', 3. 'Ecological integrity' and 4. 'Non-related' -this last category served as a 'trash category' where publications not contributing to the aims of this study were removed from the dataset (e.g. studies of speech, virtual reality, technology).

A dataset with 300 samples was manually labelled and used for evaluating the quality of the classifier (i.e. the 'gold-standard dataset'). In order to train the classifier, 200 samples were labelled and evaluated against the 'gold standard dataset'. Table 1 shows the F-Scores per category and of

overall classifier accuracy. All categories showed good performance (F= 0.65-0.73), except 'Cultural and Social wellness', (F= 0.44). The overall accuracy of the model was good (66%).

Table 1. Evaluation of the quality of the classifier based on the gold-standard data set.

Categories	Precision	Recall	F-Score	Accuracy
Health Sample	0.8	0.547	0.649	
Cultural & Social wellness Sample	0.361	0.55	0.436	
Ecological integrity Sample	0.657	0.71	0.682	
Non-related Sample	0.673	0.796	0.729	
Overall				0.658

2008 publications were evaluated, which were automatically labelled under the following categories: Health, 520 (25.90%), Cultural and Social wellness, 295 (14.69%), Ecological integrity, 295 (14.69%) and 'Non-related' categories, 898 (44.72%). As illustrated in fig. 4, 'Health' is the category that harbours the earliest research on 'soundscape' and 'wellbeing' (since the 80s), followed by a several studies in the 'Ecological integrity' category (during the late 80s and 90s) and 'Cultural and Social wellness' (in the late 90s). There were few publications between 2002 and 2003. Since then, research has grown overall, with some periods of decreasing or non-increment (such as in 2004, 2007 and 2011). A noticeable growth in the investigation on the topic seems to have occurred since 2014.

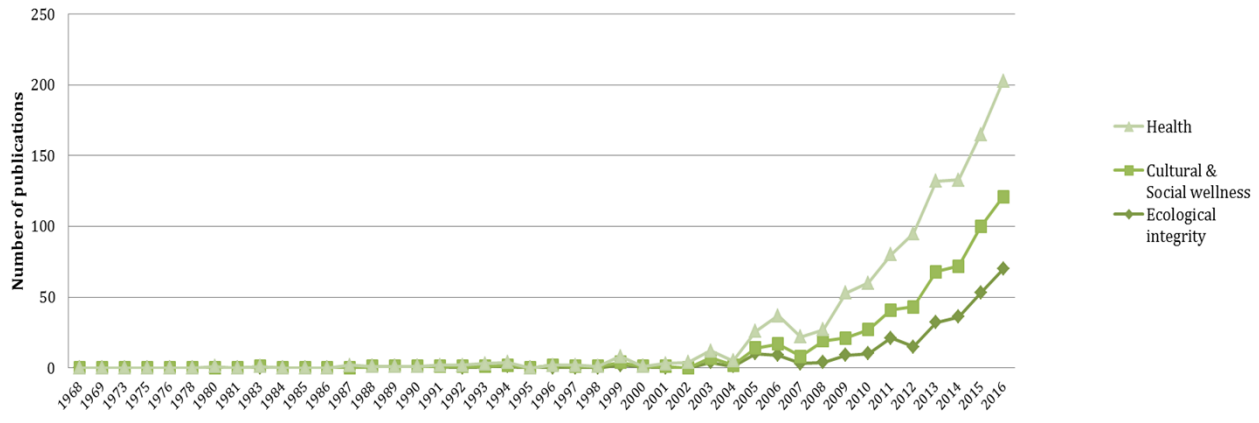

Figure 4. Number of publications reporting the association between soundscape and distinct

domains of wellbeing: 1. Health, 2. Social and Cultural wellness, and 3. Ecological integrity, based on the analysis of 'author-keywords' or 'index-keywords'.

A conceptual map of the association between 'soundscape' and 'wellbeing', based on the publication-keywords list, is presented in Figure 5. The map was separated into human and non-human species and divided into positive and negative associations, to facilitate comprehension. 'Health' associations with soundscape was the category with the highest number of keywords. The positive associations describe mainly psychological/mental states of wellbeing (e.g. tranquillity, comfort, welfare) and health benefits (e.g. attention restoration, stress recovery, rehabilitation); whereas the negative associations were based on noise and its consequences for psychological wellbeing (e.g. noise annoyance, stress, hypertension). 'Cultural and Social wellness' presented a range of positive associations that refer to individual and collective social processes (e.g. such as identity, collective memory, cultural heritage). Negative associations with wellbeing were scarce, and were related to the effects of noise, especially on communication (e.g. noise barrier, acoustic fragmentation, acoustic problems). 'Ecological integrity' was particularly associated with terms describing ecological patterns (e.g. acoustic heterogeneity, acoustic partitioning, biodiversity) and environmental status (e.g., acoustic quality, environmental health, soundscape indicator). Negative associations were describing impacts on the acoustic community (e.g. acoustic masking, acoustic niche overlap, acoustic disturbance).

HUMAN WELLBEING

Cultural & Social Wellness		Health		ECOLOGICAL WELLBEING Ecological Integrity	
Positive	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**
Acoustic comfort	Sound barrier	Aural health	Agitated	Acoustic diversity	Acoustic masking
Acoustic value	Acoustic fragmentation	Hearing impairment	Annoyance	Audiodiversity	Biological noise
Identity	Acoustic problems	Psychological stress	Anxious	Biodiversity	Nature deficit disorder
Place identity	Community noise	Rehabilitation	Environmental noise pollution	Habitat restoration	Acoustic competition
Popular Culture	Noise annoyance	Restoration	Health risk	Indicators	Acoustic disturbance
Acoustic memory	Noise barrier	Speech intelligibility	Health anxiety	Resource partitioning	Acoustic interference
Acoustic value	Noise disturbance	Acoustic comfort	Hearing loss	Urban environmental quality	Acoustic masking
Architectural heritage	Noise problems	Acoustic quality	Hypertension	Acoustic adaptation	Acoustic niche overlap
Collective memory	Social impact	Acoustic variables controls	Job stress	Acoustic heterogeneity	Acoustic noise
Communication		Amenity	Mental health	Acoustic niche	Ambient noise
Control measures		Attention restoration	Noise annoyance	Acoustic partitioning	Anthropogenic disturbance
Creativity		Aural comfort	Noise disturbance	Acoustic quality	Anthropogenic impact
Cultural heritage		Environmental quality	Noise pollution	Adaptation	Anthropogenic noise
Cultural identity		Healing environment	Physiological stress	Acoustic variables control	Community noise

Environmental benefits		Health	Road traffic noise	Animal care	Environmental noise
Ecosystem services		Human comfort	Subjective loudness	Damage detection	Environmental pollution
Efficency		Mental restoration	Sound unpleasantness	Environmental health	Habitat degradation
Indicators		Motivation	Sleep disturbance	Environmental quality	Masking
Intangible cultural heritage		Noise pollution control	Sound barrier	Environmental sound quality	Noise
Memory		Patient rehabilitation	Stress	Environmental values	Noise barriers
Noise control		Pleasure	Traffic noise	Restoration	Noise disturbance
Noise management		Public health issues	Traffic noise pollution	Sonification	Noise pollution
Noise regulation		Quality of life	Uncomfortable	Soundscape indicator	Ocean noise
Office satisfaction		Quietness	Urban noise	Soundscape quality	Ship noise
Place identity		Restoration		Species evenness	Traffic noise
Quality of life		Restorativeness		Species richness	Underwater noise
Sense of place		Satisfaction		Sustainable land use	Urban noise
Social identity		Speech production			Wind-dependent noise
Social life		Stress recovery			
Sound heritage		Tranquillity			
Urban identity		Welfare			
Use of Territory		Wellbeing			
		Work performance			

Figure 5. Conceptual map of the associations between 'soundscape' and 'wellbeing' in outcomes categories, based on keywords analysis of literature published on the topic.

4. DISCUSSION

This study analysed the largest collection of academic literature at the intersection of ecological and social research into soundscape and wellbeing to date. Based on a systematic review carried out using bibliographic software analyses tools, the origins and the evolution of research in soundscape and wellbeing are reviewed; temporal and spatial dynamics of the field were also characterized. Additionally, a classification model that describes the domains of wellbeing associated with soundscape was described.

4.1. Origin, Evolution and Dynamics of the field

Analyses reveal that research into soundscape and wellbeing has been of interest to a wide range of disciplines, as reported in Farina (2014b) and Sattar et al. (2016). Understanding of the associations between soundscape and wellbeing has changed and evolved over time: the initial term *association* reflects a research focus into the effects of sounds on the physical body and the mechanical processes associated with the senses in human and other non-human animals. This seems to be followed by the exploration of technological applications, based on acoustic research and sound measurement. Research on physical responses to sounds in humans, especially of the

effects of noise, seems to have influenced the development of research in other disciplines, such as the psychological and the social/cultural implications of sounds. Furthermore, the appearance of new research perspectives led to the wider usage of concepts, such as 'soundscape'. Likewise, research in soundscape seems to have influenced the development of studies not centred on humans, but on ecological understanding and the implications of noise in the ecosystem.

The evolution of the field, evidenced by the appearance of differing terminology through time, has occurred over a relatively short period of time. Before the 21st century publications were scarce. The appearance of a new lexicon on the subject seems to be related to the emergence of new branches of research over time, as suggested by Pijanowski et al. (2011a). The usage of the term 'soundscape' could have had an effect on the evolution of the subject and its diversification into new research avenues: initially, the study of the influence of sounds was centred mainly on negative associations of sound (i.e. noise) in humans (Farina, 2014b), but the popularization of the term 'soundscape' might have influenced the integration of other studies explaining a range of linkages between soundscape and wellbeing. That is, 'soundscape', as a multidimensional concept that includes the integration of biological, geophysical and anthropogenic sounds (Pijanowski et al., 2011b) could have had an influence on other ways of understanding and studying sound and its associations with 'wellbeing'. As a consequence, new and more integrated branches of research that include social and ecological realms (such as soundscape ecology), appeared. On the other hand, terms such as 'noise' or related words, were already present in most branches of study. The impacts of noise on health and quality of life was already identified in the late 1960s (Ward and Fricke, 1969), nevertheless, it was only after some decades that its study became popular (Passchier-Vermeer and Passchier, 2000).

Spatial analysis highlighted the influence that some nations have had on the evolution of the field. Most of the contributions have been produced in industrialized or ´developed´ countries, which can be considered as a bias of knowledge with regard to data collection or within the field of research. The scarcity of publications from 'developing countries' could be explained by three possible reasons: 1. There is a generalized trend, observed in the countries that have contributed mostly to the field, of producing most of the world's published scientific research (EU-Commission, 2003). 2. For methodological reasons the current database did not include other sources of literature, such as 'grey' literature or other bibliographic databases, which would have increased the amount of work (and knowledge) coming from 'developing' countries, and 3. Data compilation is biased by the language given that it is comprised of publications only in English. Additionally, it could be inferred that most of the associations presented in this study are referring to industrialized environments, with research on natural environments settled within urban areas.

The analysis of contributors by citation source provides an overview of the main branches associated with the development of the field, and the associations between them. As reported in Sattar et al. (2016), sound engineering has been the primary contributor to the field, with

publications on sound mechanics and noise assessment/control. Other influential contributors have been acoustics, focused on the development of technologies, sound measurement and noise control, as mentioned by Turner et al. (2013). Other contributing fields include acoustic ecology, psychology, landscape architecture and environmental sciences. Recent work, as shown by spatial and temporal analyses, include the branch of ecology and landscape ecology.

4.2. Defining categories of the association of Soundscape with Wellbeing

The analysis suggests that described associations between soundscape and wellbeing could be synthetized into three main domains ('Health', 'Cultural and Social wellness', and 'Ecological Integrity'). This classification is represented in the Lexical network, reporting academic linkages between soundscape and ecological and social wellbeing, based on the largest database of literature analysed to date. Most of the associations found in this analysis were human-based; as a consequence, and because the number of ecology-based publications was low, there was only one category proposed for the ecological realm.

It is important to consider that the increase in work published on the topic over time is also an observed trend for all academic publications: for example, the number of documents registered in SCOPUS from all documents published from 1974 to 2016 (i.e. period of time observed in the database of this study) has increased five times (from 557,315 to 278, 8202 publications).

Health

Of all the identified categories, the domain that has been better described in the scientific literature is 'Health'. This might be explained by the great number of years that the topic has been studied in comparison with the rest of the categories. This study confirmed that there has been particular interest in research on 'noise', related terms (e.g. 'noise-pollution', 'noise annoyance', 'traffic noise') and its consequences on health. Good descriptions of the impact of noise on human health have been reported in Passchier-Vermeer and Passchier (2000), Stansfeld and Matheson (2003), Fritschi et al. (2011), and Farina (2014b), which describe negative effects on physical health (such as hearing impairment, hypertension, cardiovascular disturbance, immune effects and sleep disturbance) and on mental/psychological health (such as emotional instability, task performance, stress, neurosis, annoyance, long term memory). Most of these associations were illustrated by this analysis.

It was also observed that even though research on the positive linkages of sound with health appeared years later, there was a high variety of described positive associations. Some good examples of those associations are reported in similar work by Sattar et al. (2016), Oldoni et al. (2015), Gidlof-Gunnarsson and Ohrstrom (2010) and Farina (2014), which describe how soundscape of good quality influences physical and mental/psychological health. These influences

include long-term annoyance reduction, stress prevalence reduction, restorative effects, rest, relaxation, welfare and mental health. The lists of associations obtained in this category were self-explanatory, which contributed to a general understanding of the existing relationships between soundscape and this category.

Cultural and Social wellness

The 'Cultural and Social wellness' category was comprised of a variety of aspects associated with wellbeing, which have been reviewed in similar studies (Sattar et al., 2016, Schafer, 1994, Farina, 2014b). The most relevant positive aspects considered in these reports were illustrated in this study and include sense of place (e.g. Fisher, 1999), cultural heritage (e.g. O'Connor, 2008), identity (e.g. Harmon, 2003), and communication (e.g. Fritschi et al., 2011). Additionally, other variables might reflect association with soundscape as an environmental service. Negative associations in this study were scarce, and are related to the effects of noise on communication. For example, Brammer and Laroche (2012) report how noise interferes with communication within industrial and other workplaces (e.g. open-plan offices, construction) but also within buildings (e.g. schools, residences, arenas) and describe the social implications of this. It is important to mention that this category had the lowest F-Scores (especially of *Precision*), which may need further research in order to confirm the accuracy of the described associations with soundscape. The high variance of topics (i.e. type of terms) related to this category could explain the low precision in the classification analysis. Additionally, the scarcity of data (number of publications) analysed during the elaboration of the classifier could also be related to the low scores of the analysis and the lack of negative associations found in this analysis.

Ecological integrity

The category 'Ecological integrity' comprised of aspects that might be related to patterns occurring in natural ecosystems. These linkages highlight the basis of the fields of soundscape ecology and ecoacoustics, in which soundscape is studied as a proxy of biodiversity and of habitat status, by generating quantitative and qualitative measurements of sound or 'acoustic indices' (e.g. Sueur and Farina, 2015, Sueur et al., 2014b, Kendrick et al., 2016, Sattar et al., 2016). The negative associations observed were mostly descriptions of the impact that noise or anthropogenic activities have on the environment and on acoustic communities, including ocean noise, which has been well reported within bioacoustics (Au and Hastings, 2008). It is important to mention, given that the categories 'Ecological integrity' and 'Animal health' were combined into one category, that other associations with wellbeing might not have been highlighted. For example, work on the impact of underwater noise on the behaviour and hearing loss of whales (e.g. Moore and Clarke, 2002, Erbe, 2002, Aguilar Soto et al., 2006), would have been classified within the 'Animal Health' category, but now is classified within the category 'Ecological integrity' which is less specific. In general terms, it was difficult to define the positive associations within this category as the terms are not

self-explanatory or not so evident, but after reviewing material on the topic (e.g. Dumyahn and Pijanowski, 2011, Farina, 2014b, Sueur and Farina, 2015) it was easier to classify them.

4.3. The use of technological tools for reviewing large collections of publications

The use of technological tools for conducting this systematic literature review allowed us to: 1. Analyse a large compilation of data in a short period of time with reduced research effort compared to a traditional literature review methodology, which may require longer periods of time and participation of multiple researchers (e.g. McKinnon et al., 2016), 2. Synthesise relevant information published on the topic such as key-concepts and relevant terminology. In particular, the use of keywords was confirmed as a useful means for extracting essential information from literature as they highlight relevant content in each publication (Wartena et al., 2010), 3. Understand the multiple dynamics of the field of research through bibliographic network maps, 4. Identify the lacunae/gaps in research. Furthermore, the visualization map made interpretation of the results easy. Additionally, the use of technological tools might facilitate comprehension of the topic for people with lack of expertise in the field, by extracting relevant concepts in a concise and precise way.

The limitations of the use of technological tools found during this study are the following: 1. The outcome (i.e. term extraction) sometimes could be ambiguous and depends on the interpretation of the analyst. For example, some terms have a different meaning, depending on the context of the topic. As a consequence, the probability of misinterpreting terms could be high; 2. The extraction of terms from each publication could limit the understanding of the field in depth. During the analyses, it was often necessary to read the whole abstract in order to better understand the definition of the keyword; 3. The analyses required a specific format of data compilation which is only provided by the SCOPUS and Web of Science, hence, data compilation from other published/unpublished sources is constrained; 4. In order to run the analysis, it was necessary to have a minimum amount of publications; as a consequence, specific topics with low numbers of publications (e.g. animal health) were considered within a bigger (or better studied) topic or research, obviating detailed analysis.

4.4. Gaps and limitation of the study

The systematic review presented in this study identified gaps in literature compilation which might reflect limited or lack of publications in particular research areas. In this study two main gaps or biases were observed: 1. Most of the studies were conducted by academic institutions from ‘developed countries’ and 2. Literature based in the ecological and social/cultural realms was scarce. These limitations may reflect the current status of knowledge of the field, but at the same time stimulates future investigation. Work in these areas may extend the understanding of the association between soundscape and wellbeing. It is important to also consider that gaps might be

a consequence of a constrained search strategy. As discussed above, this study did not include information published in additional databases and in 'grey' literature, due to software requirements. Furthermore, it did not include other languages, which could be a bias particularly of publications conducted in non-western societies. Additionally, although keyword analysis provides relevant information on each publication, it does not cover all the theoretical thinking associated with this topic; as a consequence, important information published on the topic might not be considered within this framework.

This work should be taken as a general framework with which to understand the current status, with respect to academic material published on the field, of the associations between 'soundscape' and 'wellbeing'. Subsequent studies should be more exhaustive in terms of data compilation, and also consider delving more deeply into the content of the publications in order to improve the understanding of the proposed conceptual model of the linkages between 'soundscape' and 'wellbeing'.

5. CONCLUSION

This study characterized the status of knowledge on the field of soundscape and its associations with ecological and social wellbeing. In spite of the fact that research on sound and its impact on human health has had a long trajectory within academia (Ward and Fricke, 1969), it is only since the 21st Century that the topic has been studied in detail. The aim of this work was to bring together knowledge produced across disciplines that have contributed to the topic, in order to explain the origins and evolution of the field; and also understand the existing linkages, gaps and frontiers of knowledge. The outcome of this study illustrates how research on the topic originated from having a primarily medical/physiological focus, mainly oriented to human research, into a technological and psychological/social focus, and finally widening to include an ecological/social focus. Work published on the subject comprises of a number of branches, which are related, and influence each other to differing degrees. Furthermore, the diversification of the field into branches seems to be related to the evolution of the topic which, at the same time, brought into use new concepts and terminology. It was clear how research evolved from studying particular associations between sound and health (mainly focused on noise and related topics), to multidimensional and integrative research on soundscape and its linkages with wellbeing. This development allowed the incorporation of a wider spectrum of topics, beyond the humanities driven focus, based on the concept of ecological wellbeing. The appearance of ecological-based research was influenced mostly by research from human-based disciplines (Pijanowski et al., 2011a).

The conceptual map presented comprises a range of associations between soundscape and wellbeing which are synthetized into three main categories: 'Human health', 'Social and Cultural wellness' and 'Ecological integrity'. The first category was the most representative, better understood and oldest topic explored over time; it is based on physical and physiological influences

of soundscape on health. 'Social and Cultural wellness', is characterized by a range of associations, that describe individual and collective processes, based on aspects of identity, sense of place, memory, cultural heritage and social communication. Despite the high variety of associations found in this category, the number of publications on the topic was low. The category 'Ecological integrity' encompassed associations describing patterns of environmental communities and the influence of anthropogenic activities on them. Whilst these associations might be not so evident to comprehend in comparison with other categories, they suggested aspects of wellbeing influenced by 'high quality soundscapes', as reported in Dumyahn and Pijanowski (2011). More work on these associations should be addressed in the future in order to increase comprehension, as the study of 'ecological wellbeing' is relatively new. There is no clear concept of what 'ecological wellbeing' involves, yet scientists use a range of synonyms, such as 'biological/ecological/ecosystem integrity', or 'ecological/ecosystem health' to describe the ability of an ecosystem to support and maintain ecological processes and a diverse community of organisms (Karr, 1991). Moreover, there is no consensus of how to measure it, therefore results on the topic are scarce.

This work reports the largest analysis of the relationship between soundscape and ecological/human wellbeing to date. It could be considered as a reference for further work on the topic, especially within the field of soundscape ecology, which promotes research on the implications of soundscape conservation on wellbeing (Dumyahn and Pijanowski, 2011). The methodology used in this study is shown to be an effective tool for analysing large collections of data in short periods of time. With these tools the main questions of the study were addressed by extracting and synthesizing relevant concepts/terms generated by the topic; nevertheless, it was necessary to delve deeply into literature to understand the ambiguities or non-self-explanatory terminology. Further work is necessary in order to complete/improve the framework generated on the topic, in particular by including other sources of information (i.e. databases or 'grey literature') that were not considered in this study, and publications in other languages. Furthermore, several gaps in research were observed in the analyses; further research is recommended in order to develop a more comprehensive understanding of the associations between soundscape and wellbeing, such as information generated by non-western societies, and exploration of the ecological and sociocultural aspects of wellbeing.

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